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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G21K 1/06

A1

(11) International Publication Number: WO 00/63922

(43) International Publication Date: 26 October 2000 (26.10.00)

(21) International Application Number: PCT/GB00/01574

(22) International Filing Date: 20 April 2000 (20.04.00)

(30) Priority Data:
9909052.4 20 April 1999 (20.04.99) GB

(71) Applicant *(for all designated States except US)*: COUNCIL FOR THE CENTRAL LABORATORY OF THE RESEARCH COUNCILS [GB/GB]; Chilton, Didcot, Oxfordshire OX11 0QX (GB).

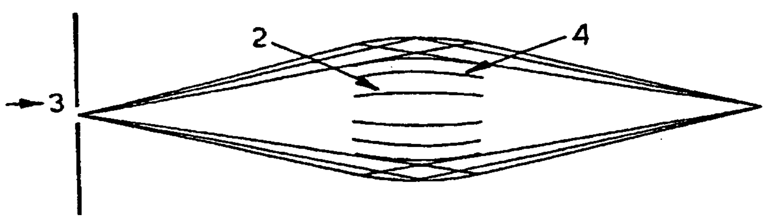
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: JOHNSON, Michael, W. [GB/GB]; 16 Highmoor Road, Caversham, Reading, Berkshire RG4 7BN (GB). DAYMOND, Mark, Richard [GB/GB]; 71 a Walton Street, Oxford, Oxfordshire OX2 6AG (GB).

(74) Agents: PERKINS, Sarah et al.; Stevens Hewlett & Perkins, Halton House, 20/23 Holborn, London, Greater London EC1N 2JD (GB).

(81) Designated States: GB, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: NEUTRON LENS



(57) Abstract

A neutron lens comprises a series of silicon wafers (2), each preferably shaped to describe a two dimensional ellipsoidal surface, with a neutron reflecting coating (4) sandwiched between adjacent wafers. The wafers are arranged so that their major axes are approximately aligned with the neutron beam direction. The wafers of silicon act as conduits for the neutrons and also provide structural surfaces to which the neutron reflecting coating (4) is applied. With the neutron lens the gauge volume can be defined with a higher flux of neutrons than has previously been possible.

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NEUTRON LENS

The present invention relates to a neutron lens and in particular to a neutron lens constructed using silicon based material.

While neutron scattering is often the technique of choice for many condensed matter investigations a persistent problem is the fact that, in comparison to modern light sources, neutron sources are very weak. As a consequence neutron beam experiments tend to require larger samples, and take longer to run..

Neutron sources have been developed over the years and there is currently under construction third generation pulsed spallation sources which will offer increases of between x10 and x30 over existing neutron sources. However, this source increase must be combined with improvements in instrumentation of a similar magnitude to ensure effective gains of around x1000 which is the order of gain required to study many of the most pressing and interesting problems that occur in condensed matter science. Instrumentation improvements have been achieved through increases in detector area and pixellation, the use of focussing monochromators and the provision of new neutron optical devices such as super-mirror guides. However, other than neutron guides, there are few devices for de-coupling the divergence of the neutron beam from its flight path. Such de-coupling is extremely important for optimal instrument design on pulsed sources since both the divergence and flight path play a role in determining the intensity and resolution of the neutron scattering instrument and maximising performance often requires that they be adjusted separately.

Currently, neutron focussing optical devices have used Bragg diffraction, refraction or reflecting capillaries such as micro channel guides (Kumakhov lens) or 'Lobster- Eye' optics. The Bragg diffraction and refraction lenses use wavelength dependent effects that are unsuited to white beam instrumentation. Such lenses would not therefore be generally useful in time-of-flight sources such as ISIS (at the Rutherford Appleton

useful in time-of-flight sources such as ISIS (at the Rutherford Appleton Laboratory, UK) or the third generation sources such as the SNS being developed in the US.

Kumakhov lenses, on the other hand, use grazing incidence multiple reflection within capillaries to guide neutrons to a focal point. Kumakhov lenses are well suited to white beam instrumentation, but achieve their gains by intercepting a large beam area, and, with relatively low efficiency, increasing the flux of neutrons at a focal point through a large increase in the divergence of the neutron beam. Such divergence can be greater than 0.1 rad. US5497008 describes a Kumakhov lens that consists of hollow capillaries through which the neutrons pass and are focussed. US 5658233 describes the use of a similar capillary neutron lens in medical applications.

More recently in volume 10, No. 1 1999 of Neutron News an article entitled “Novel Optics for Conditioning Neutron Beams II: Focussing Neutrons with a ‘Lobster-Eye Optic”, B E Allman et al described a lens constructed from a microchannel plate (MCP) array of lead-glass square channels. While such a lens does produce a focussing effect. The solid angle of acceptance of the lens is set by the relatively low, grazing incidence reflection from the glass surfaces.

The present invention seeks to provide an improved neutron lens, based on reflection, that is suitable for use with white beam spallation neutron instrumentation, that does not have the problem of divergence associated with Kumakhov lenses and that is less complex and costly to construct than existing neutron lenses.

Thus the present invention provides a lens for focusing particle or electromagnetic radiation comprising a plurality of transmissive layers arranged in a stack and a plurality of reflective layers each interposed between respective adjacent transmissive layers, each reflective layer being applied to a surface of a transmissive layer.

In a first aspect the present invention provides a neutron lens

comprising a plurality of reflective layers of neutron reflective material separated by transmissive layers of a material containing silicon.

The present invention enables a well defined small volume of a sample to be reliably illuminated with neutrons with components that need not be in contact with or close to the sample itself. Furthermore, with the present invention the total solid angle of neutrons incident on a sample is greater than can be achieved with existing lenses. The present invention also provides an improved signal-to-noise performance as the neutron beam can be restricted to that strictly required to illuminate the sample.

Ideally, the transmissive layers, arranged to lie generally parallel to an incident neutron beam, consist of single crystal silicon material. The reflective layers preferably consist of a metallic coating such as Ni or consist of a supermirror coating.

In a preferred embodiment the surfaces of the transmissive layers on which neutron reflective coatings are formed are elliptical or parabolic in shape. The thickness of individual transmissive layers may vary whilst the surface area of the reflective coatings may be substantially equal. Alternatively, the thickness of the transmissive layers may be substantially equal whilst the surface areas of the reflective coatings may vary.

Preferably, individual reflective layers are separated a distance of between 10 microns and 1 mm. More preferably, where the thickness of the transmissive layers is substantially equal, the individual reflective layers are separated a distance of between 30 to 80 microns, ideally 50 microns.

In a further aspect the present invention provides an x-ray lens comprising a plurality of reflective layers of x-ray reflective material separated by x-ray transmissive layers. Ideally, the transmissive layers consists of a material containing beryllium.

Embodiments of the present invention will now be described by way of example with reference to and as shown in the accompanying drawings, in which:

Figure 1 is a schematic diagram of a neutron lens employing 2-D

ellipsoidal surfaces;

Figure 2 is a schematic 3-D diagram of the neutron lens of Figure 1;

Figure 3 is a schematic diagram of an alternative neutron lens which employs double parabolic surfaces; and

Figure 4 is a schematic diagram of a second alternative neutron lens which employs plane surfaces of varying length.

The neutron lens shown in Figure 1 consists of a plurality of layers 2 of a material containing or consisting of silicon such as silicon wafers generally aligned with the beam path of the neutrons from a source 3 so that the surface area of each layer approximately lies in the plane of the incident beam. On one surface of each silicon layer 2 is a neutron reflective coating 4 such that each coating layer is sandwiched between and in contact with the silicon layer to which the coating is applied and an adjacent silicon layer. The outermost layers of the lens are of silicon. The neutron lens includes no through apertures or channels exposed to the air/vacuum surrounding the lens, instead the neutron lens is a solid with consecutive, generally aligned stratae of silicon 2 and the reflective coating 4. Silicon is used because it is substantially transparent to neutrons over a wavelength of 1 Angstrom, it can provide a mirror surface for the deposition of supermirror coatings, and can be produced in a variety of thicknesses. Furthermore, Si wafers are preferred because they may be bent, to achieve the optical surfaces required. Such curvature may be achieved by profiling the Si wafer thickness, or by placing suitable packing pieces between the layers of the lens. Thus, the silicon layers act as conduits to the neutrons and provide structural surfaces to which the neutron reflecting coating is applied.

As can be seen from Figure 1, each silicon layer 2 is curved to define a 2-D ellipsoidal surface for the reflective coating 4. The elliptical surfaces to which the reflective coating is applied ensure improved neutron intensity at the image point with an angle of incidence equal to $\pm\theta_c$.

The construction of the neutron lens of Figure 1 can be more clearly

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seen in Figure 2. Silicon wafers on which reflective coatings 4 have already been applied, are layered about a central silicon spacer or former 5. The stack of silicon wafers is then clamped in place within a frame 6 that urges the silicon layers to conform to the shape of the central former 5.

The thickness of the silicon wafers 2 may vary in dependence on their position within the stack. Thus, as may be seen in Figure 2, the wafers are thinner the closer they are to the central former 5. The thickness may vary from as small as 10 microns up to 1 mm, for example. Generally, the surface area of the wafers is selected so that the wafers are easy to handle. For example, the wafers may be around 20-30mm along the beam and 20-70mm across the beam. However, there is no limitation on the surface area of individual silicon layers.

Alternatively, the silicon layers 2 may be shaped to define double parabolas on their surfaces, as shown in Figure 3. Such an arrangement will image an aperture with a beam divergence twice that of the elliptical design of Figures 1 and 2 and so can provide significant increases in flux.

More simplified designs are also envisaged using plane surfaces. In its simplest arrangement, the neutron lens consists of a plurality of substantially parallel layers of silicon material. Each layer is of substantially identical thickness and size, and each sandwiches a reflection coating 4. This structure is useful for certain applications but has certain disadvantages not least that not all the neutrons are scattered and a line object is not imaged as a line but is spread an amount proportional to the mirror depth.

As shown in Figure 4 the neutron lens may consist of layers of silicon material of differing surface area. Thus, the innermost layers of silicon have the greatest area and the outermost layers the smallest area. The wafers may vary in size from 5mm to 50mm in the direction of the beam and from 20mm to 70mm across the beam direction. In this arrangement the layers are of substantially equal thickness at around 50 microns.

Preferably, single crystal silicon is used in the individual layers of the neutron lens. Amorphous silicon may alternatively be used. Doped silicon is not needed and can prove a hindrance to good transmission of the neutrons. The neutron reflective coating may consist of a coating of Ni with a coating thickness of around 100nm. Preferably, though, a supermirror coating is employed using a magnetron sputtering system which is a well known technique. For example, alternate graded layers of Ti and Ni may be applied to the surfaces of the silicon wafers.

The neutron lenses described above are particularly suited to the field of engineering science where it can be used in neutron strain scanning to determined residual stresses in materials. Such studies require a small 'gauge volume' within the sample material to be defined so that the stress within that volume may be determined and the process repeated over the whole sample by scanning and measuring the stresses for each gauge volume in turn. With the neutron lens described above, the gauge volume can be defined with a higher flux of neutrons than has previously been possible. In combination with super-mirror optics such as ENGIN-X at ISIS, the neutron lens can achieve a gain in the range of 5 to 10. When small gauge volumes of less than 1mm are required the gains from using the neutron lens can be a factor of 5 to 50, even when the beam is focused in only one plane.

The neutron lens will enable smaller gauge volumes to be studied so that even crack tips, surface coatings and steep stress gradients in welds can be studied. The neutron lens could also be used in the study of new pharmaceutical compounds, for example, where the size of a single crystal is strictly limited.

The neutron lens can also increase the solid angle and hence the flux of neutrons in neutron scattering experiments. For example, the SXD instrument at ISIS is 8m from the moderator which is simply directly viewed by the sample. In this arrangement the sample is illuminated by a solid angle of 0.00016sr. Using two double parabolic neutron lenses, as

described above, the solid angle can be increased to 0.0016sr thereby providing a theoretical gain of x10 in flux and improved signal to noise. The signal to noise improvements should not be ignored as it is estimated that in many scattering experiments the penumbra surrounding the neutron beam is 20-50% of the beam intensity. Removal of a 20% background level is believed to be the equivalent of a x3 increase in flux.

Reference has been made above to neutron lens, however, the same structure of lens may be used in the focussing and conditioning of x-rays. However, for x-rays the silicon layers are replaced with layers of a material containing or consisting of Be.

It will of course be appreciated that the spirit and scope of the invention is not limited to the embodiments of lenses described above. The structure and design of the individual layers of the lens may be altered as necessary to provide the desired conditioning of the neutron or x-ray beam.

CLAIMS

1. A lens for focusing particle or electromagnetic radiation comprising a plurality of transmissive layers arranged in a stack and a plurality of reflective layers each interposed between respective adjacent transmissive layers, each reflective layer being applied to a surface of a transmissive layer.

2. A neutron lens comprising a plurality of reflective layers of neutron reflective material separated by transmissive layers of a material containing or consisting of silicon.

3. An x-ray lens comprising a plurality of reflective layers of x-ray reflective material separated by transmissive layers of a material containing or consisting of beryllium.

4. A lens as claimed in any one of the preceding claims, wherein each reflective layer is a coating applied to a surface of a respective transmissive layer.

5. A lens as claimed in claim 4, wherein the coated surface of each transmissive layer substantially describes an ellipse.

6. A lens as claimed in claim 4, wherein the coated surface of each transmissive layer substantially describes one or more parabolas.

7. A lens as claimed in either of claims 5 or 6, further including a former with the transmissive layers stacked on opposing sides of the former, the sides of the former having a profile substantially corresponding to the desired shape of the coated surfaces of the transmissive layers.

8. A lens as claimed in any of the preceding claims wherein the thickness of the transmissive layers varies with respect to the position of each layer in the stack.

9. A lens as claimed in claim 8, wherein the thickness of the transmissive layers varies between 10 microns and 1 mm.

10. A lens as claimed in any one of the preceding claims wherein the surface area of the transmissive layers in the plane of the incident radiation varies with respect to the position of each layer in the stack.

11. A lens as claimed in claim 2 and any one of claims 4 to 10, wherein the transmissive layers consist of single crystal silicon.

12. A lens as claimed in claim 2 and any one of claims 4 to 11, wherein the reflective layers consist of a metallic coating of nickel.

13. A lens as claimed in any one of claims 1 to 11, wherein the reflective layers are supermirror coatings.

Fig.1.

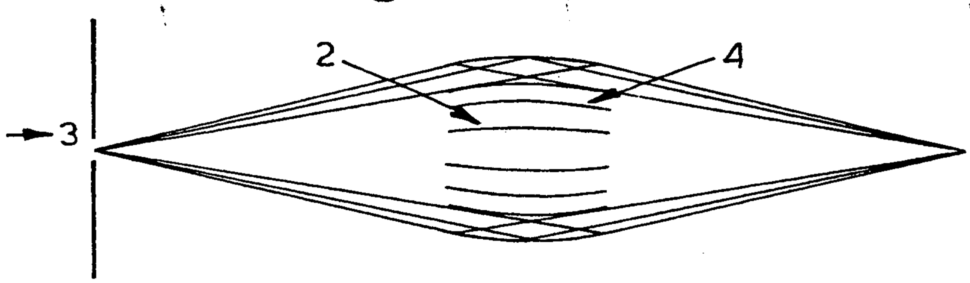


Fig.2.

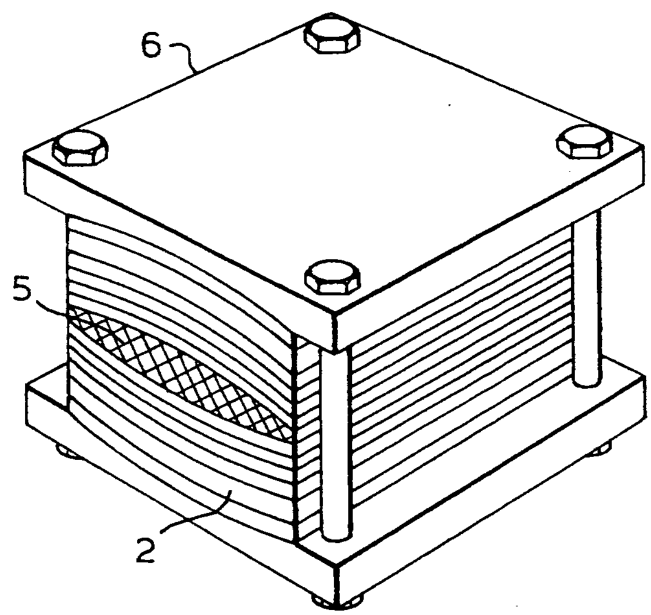


Fig.3.

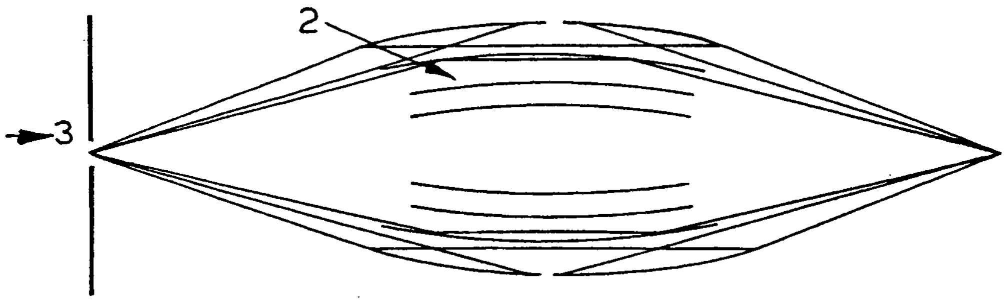
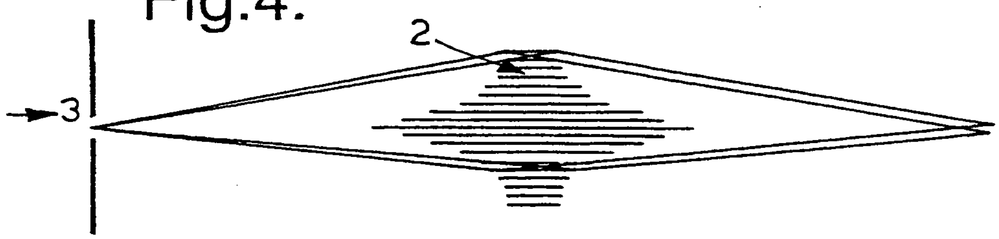


Fig.4.



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INTERNATIONAL SEARCH REPORT

Intern   nal Application No
PCT/GB 00/01574

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G21K1/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G21K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MILDNER D F R: "The neutron microguide as a probe for materials analysis" SEVENTH SYMPOSIUM ON X- AND GAMMA-RAY SOURCES AND APPLICATIONS, ANN ARBOR, MI, USA, 21-24 MAY 1990, vol. A299, no. 1-3, pages 416-419, XP000200349 Nuclear Instruments & Methods in Physics Research, Section A (Accelerators, Spectrometers, Detectors and Associated Equipment), 20 Dec. 1990, Netherlands ISSN: 0168-9002	1,2,4, 11,12
Y	page 417, left-hand column, paragraph 3 page 418, left-hand column, paragraph 1	13
A	page 418, left-hand column, last paragraph -right-hand column, paragraph 1	5,6,9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 August 2000	05/09/2000

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MILDNER D F R: "NEUTRON FOCUSING USING MICROGUIDES" NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH, SECTION - A: ACCELERATORS, SPECTROMETERS, DETECTORS AND ASSOCIATED EQUIPMENT,NL,NORTH-HOLLAND PUBLISHING COMPANY. AMSTERDAM, vol. A297, no. 1 / 02, 15 November 1990 (1990-11-15), pages 38-46, XP000177790 ISSN: 0168-9002	1,2,4, 11,12
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/01574

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